805 MHz β=0.47 Elliptical Accelerating Structure R&D

(R&D Category: Driver Linac)

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Outline

- **Objective of R&D**
- **Elliptical cavities for RIA**
  - $\beta = 0.47$ (RIA)
  - $\beta = 0.61$ & 0.81 (SNS)
- **$\beta = 0.47$ R&D program**
  - Cavities
  - Cryomodule -- realistic operating conditions

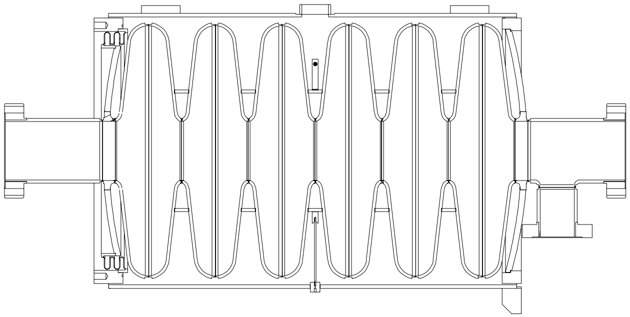
Objective

- **Carry out R&D on critical long-lead items whose demonstration is required to confidently cost and build RIA**
    - Limited R&D funds
    - Limited time
- **Demonstrate all cavities in cryomodules**
    - Near term within budget constraints
    - Realistic operating conditions
        - Horizontal cryomodule, tuner, couplers, microphonics control, ……

805 MHz Elliptical Cavities [1]

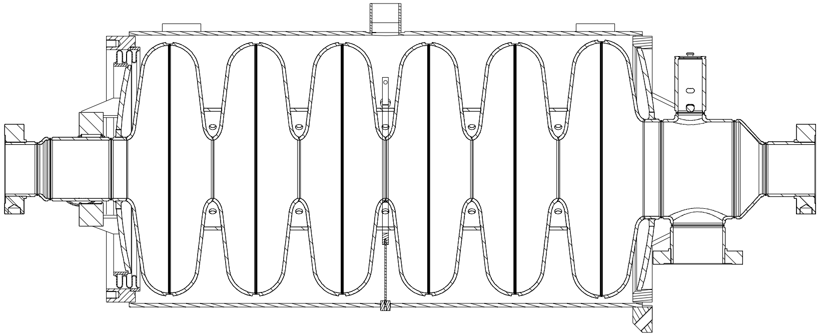
- **Elliptical cavities part of original design**
  - 700 MHz (Shepard, SRF 1999)
  - 805 MHz (Leemann, Linac 2000)
- **Accelerate beam from 85-400 MeV/u (β~0.40-0.72)**
  - ~75% of the driver linac voltage
    - Majority of that voltage from SNS cavities
  - ~1,000 MV of elliptical accelerating gradient
- **Leverage SNS & CEBAF upgrade R&D**
  - Save non-recurring R&D and engineering costs
  - Reduce technical risk
  - Capitalize on Jefferson Lab's capabilities

805MHz Elliptical Cavities [2]



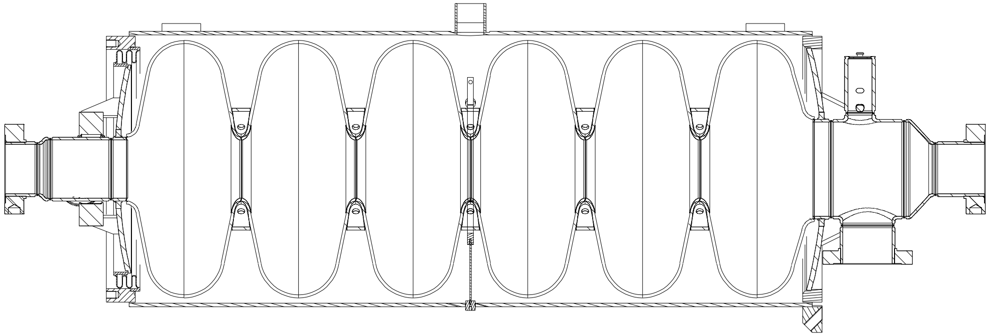
β_{geo}=0.47

RIA (MSU/JLAB)



β_{geo}=0.61

SNS (JLAB)



β_{geo}=0.81

SNS (JLAB)

805 MHz Elliptical Cavities [3]

- **Additional advantages**
  - Accelerate protons to >1 GeV using β=0.81 cavities
  - Large aperture, 77 mm
    - Room temperature quads between cryomodules
    - Easy alignment & diagnostics
  - No higher-order-mode dampers required
    - Large aperture & low intensity, cw beam
  - Fixed power coupler
    - Simple & no cavity multipacting barriers
  - Microphonics control
    - Level demonstrated for CEBAF upgrade, Q_{ext}~$2x10^7$

805 MHz Elliptical Cavities [4]

805 MHz Elliptical			
Type	6-cell	6-cell	6-cell
β_{geo}	0.47	0.61	0.81
β_{opt}	0.49	0.63	0.83
f (MHz)	805	805	805
V_{acc}(MV)	4.3	6.9	11.1
T(K)	2	2	2
Q_o	$5x10^9$	$5x10^9$	$5x10^9$
P_o(W)	21.4	34	51.4
U(J)	21.1	33.6	50.8
R/Q(Ω)	173	279	483
R_s(nΩ)	31	36	52
E_{peak}(MV/m)	27.3	27.4	26.9
B_{peak}(mT)	53.9	57.8	58.1

$$P_o = \frac{V_{acc}^2}{R}$$

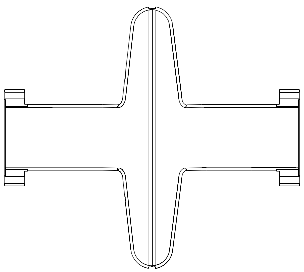
$$Q = \frac{\omega U}{P_o}$$

$$\frac{R}{Q} = \frac{V_{acc}^2}{\omega U}$$

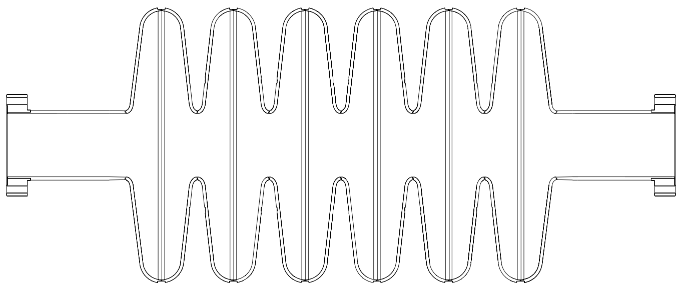
$$V_{acc} = \frac{1}{q}\left|Maximum\ energy\ gain\ of\ optimum\ particle\right|$$

β=0.47 R&D Program [1]

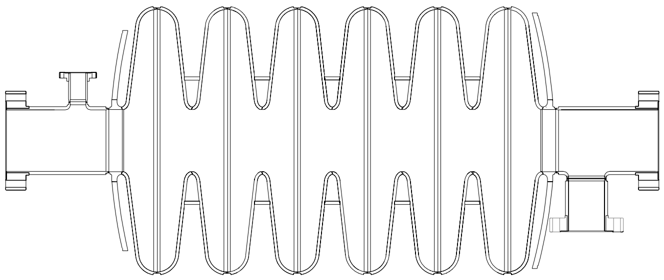
- Started in 2000 (MSU, JLAB, & INFN Milan)



(2) Tested in 2001



(1) Tested in 2002



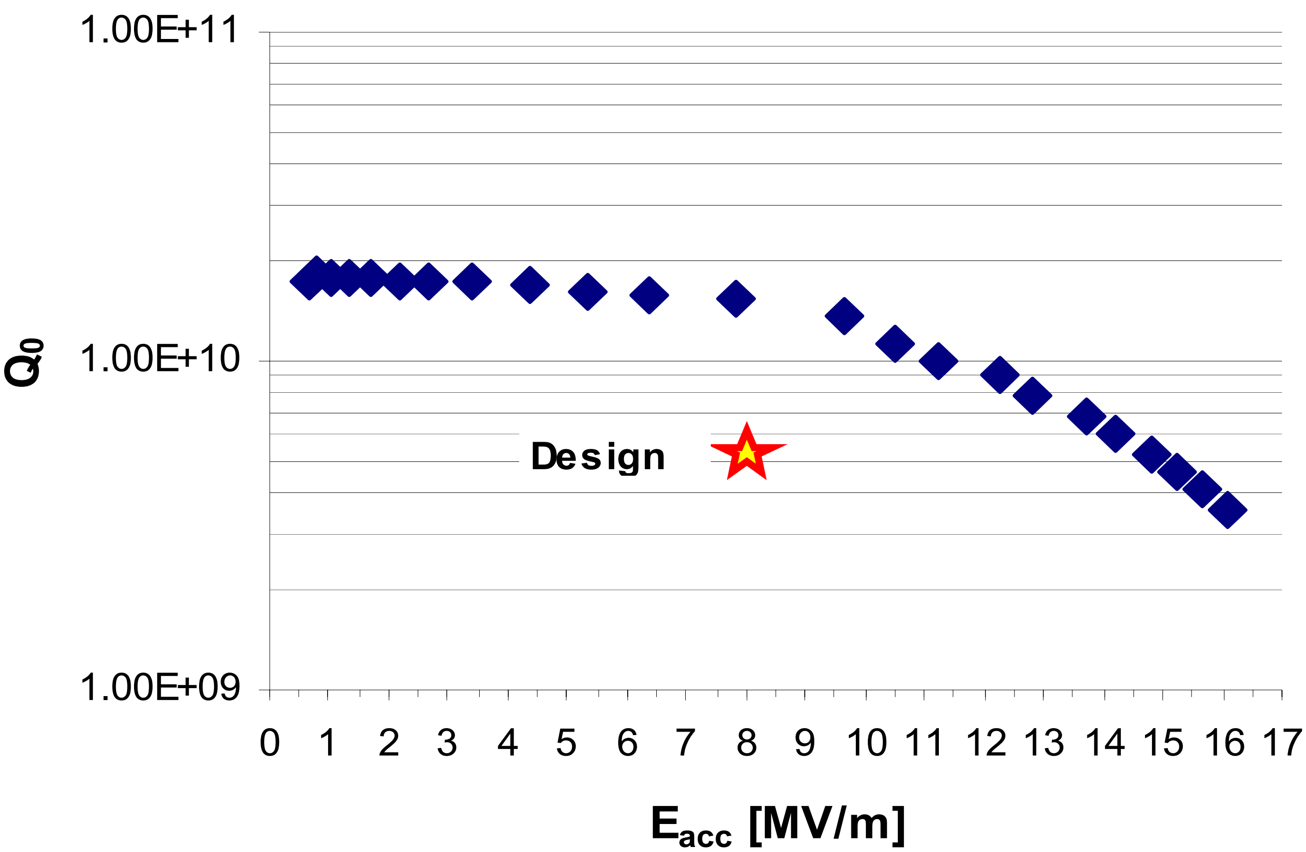
(2) Tested in 2003

- Vertical testing has been successfully completed

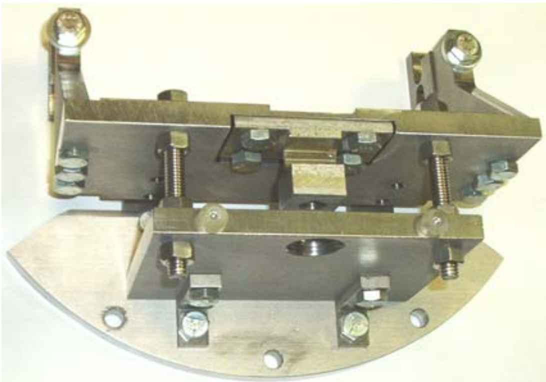
- Next step – horizontal cryomodule/realistic operating conditions

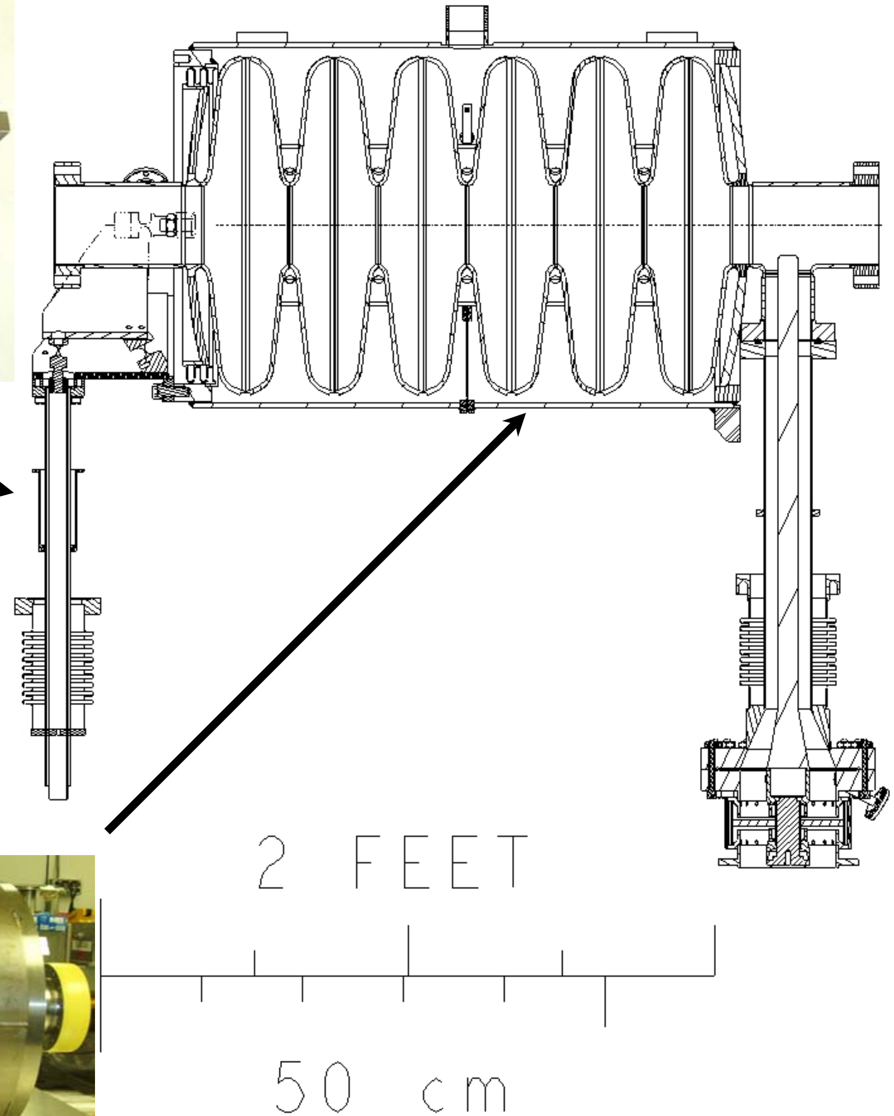
β=0.47 R&D Program [2]

e-beam welding and first test performed at JLab



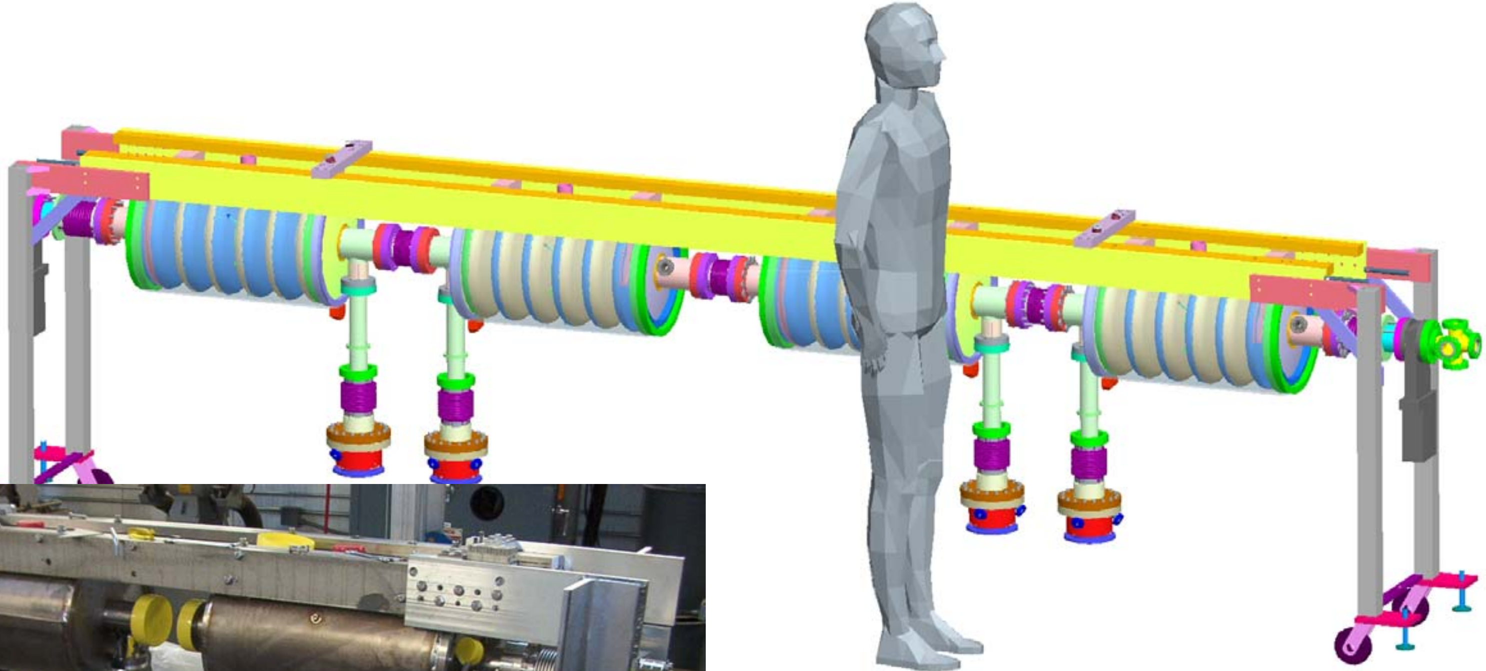
β=0.47 Tuner-Cavity-Power Coupler

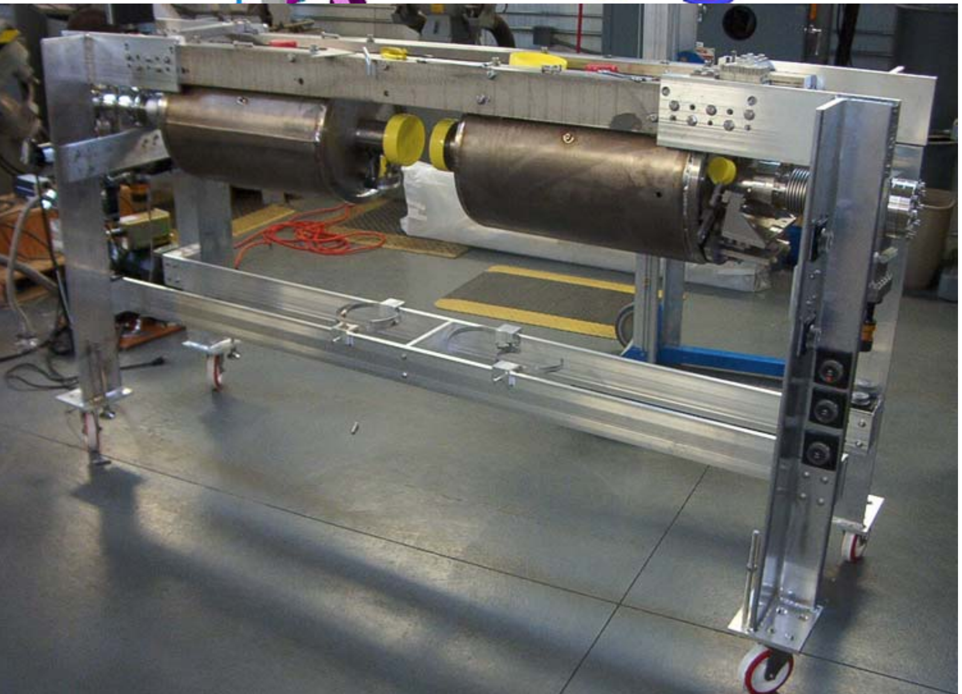




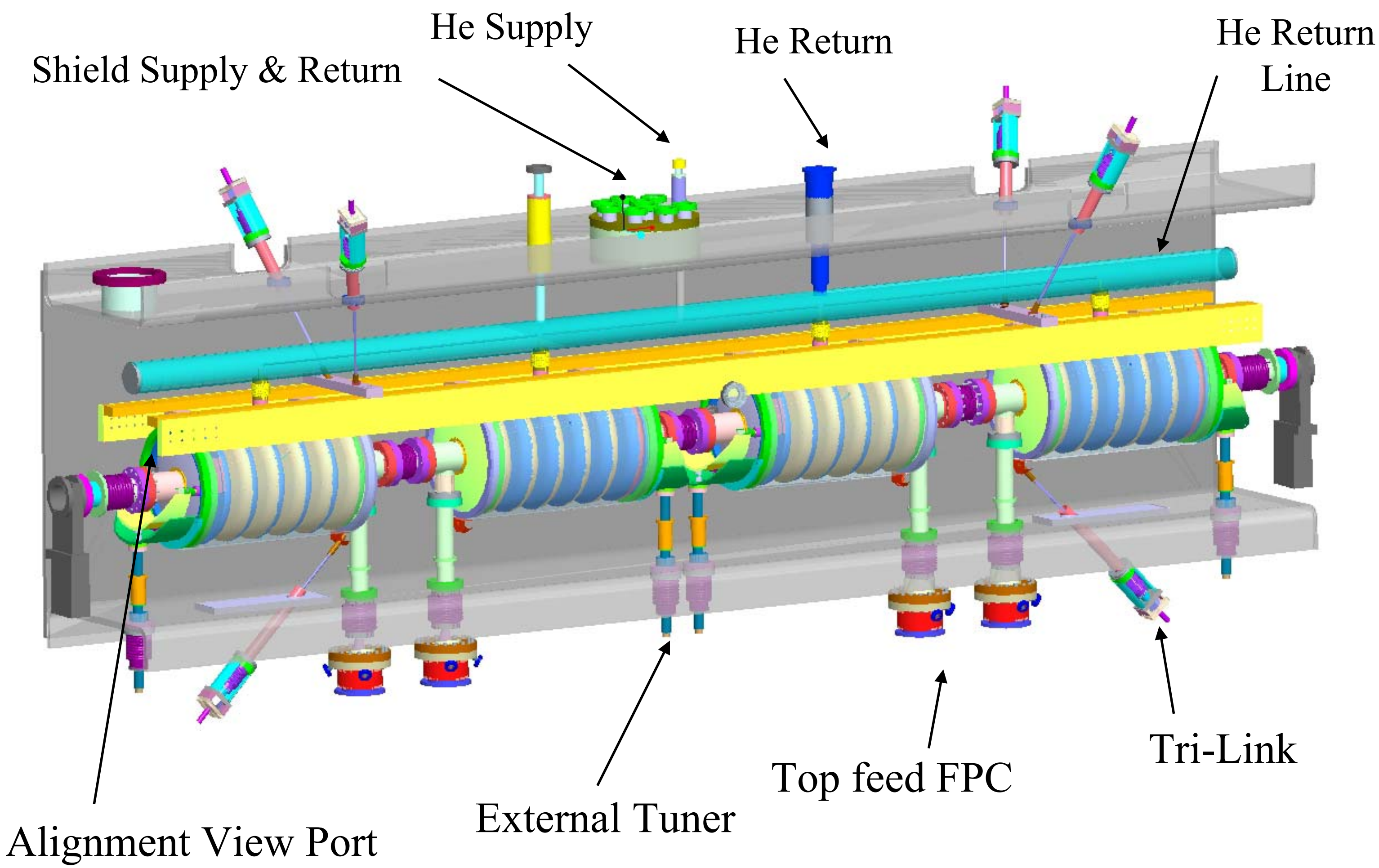
β=0.47 He Vessel at JLAB

β=0.47 Module Clean Room Assembly





β=0.47 4-Cavity Module [1]



β=0.47 4-Cavity Module [2]

Cavity	
Frequency	805 MHz
v/c = β	0.47
He Vessel Diameter	0.362 m
Total Mass	71.6 kg
Beam Aperture	0.077 m
Design Q	5×10^9
V_{acc}	4.2 MV
RF loss	22 W
Input RF power	<10 kW
Cryogenic Module(4 cavity)	
Length	4.0 m
2K Cold Mass	400 kg
Total Module Mass	3000 kg
# Bayonets	4
# Support Links	6
2K Heat Load	
Power Coupler	1.6 W/ea
Tuner	0.8 W/ea
Total / RF OFF	15 W
Total / RF ON	103 W
Shield Heat Load	<100W
Pressure Rating	
2K System	3 bar
Thermal Shield	10 bar

Power Coupler	
Impedance	50 Ω
Type	Planar Coax - KEK / SNS
Cooling	conduction
Q_{ext}	2×10^7
Bandwidth	40 Hz
P_{design}	5 kW
P_{max}	100 kW
Tuner	
Type	External / 300K
Range	500 kHz
Tuning Coefficient	> 200 kHz / mm
Cavity Spring Constant	< 10,000 lbs / in
Resolution	1 Hz
Max Force on Cavity Flange	223 kg
Force Reduction Factor	0.7

β=0.47 Module Cross-Section

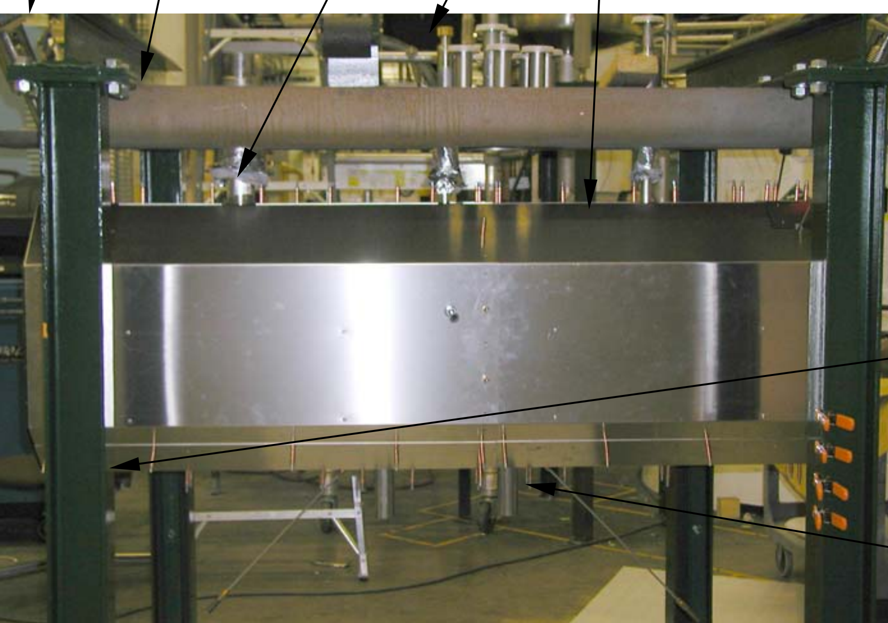
Support Link

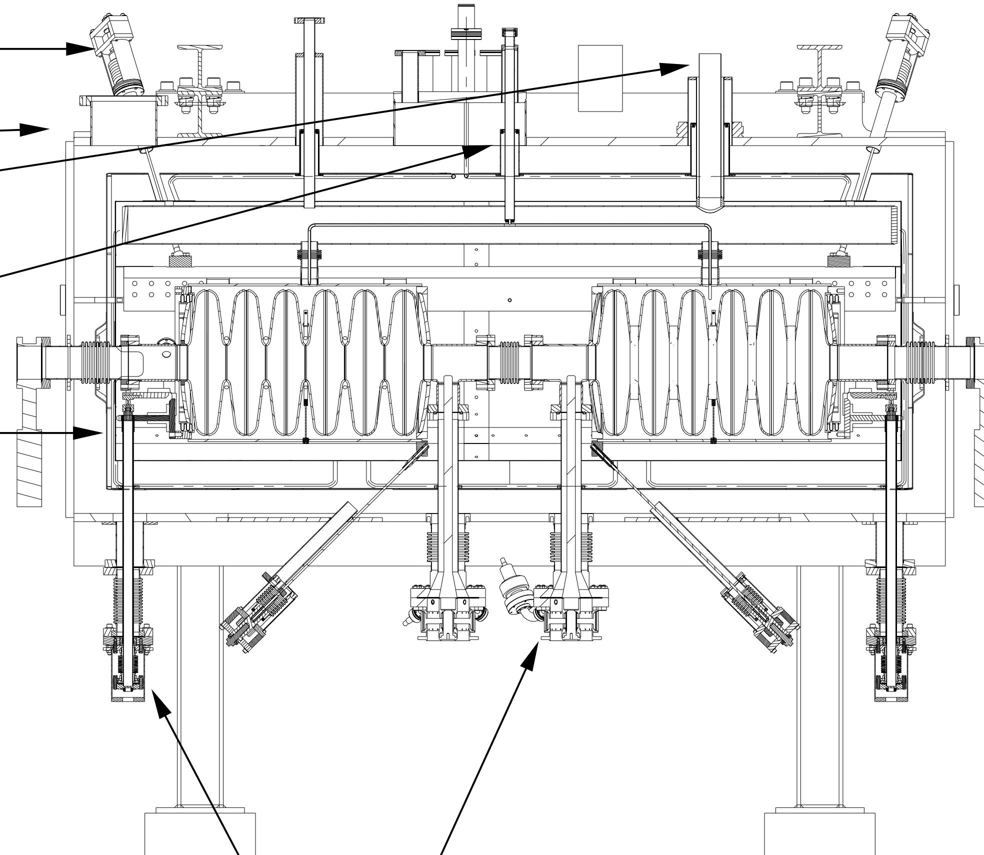
Top Plate

He Return

He Supply

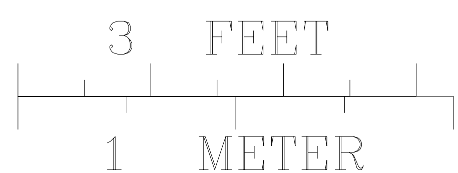
Magnetic Shields



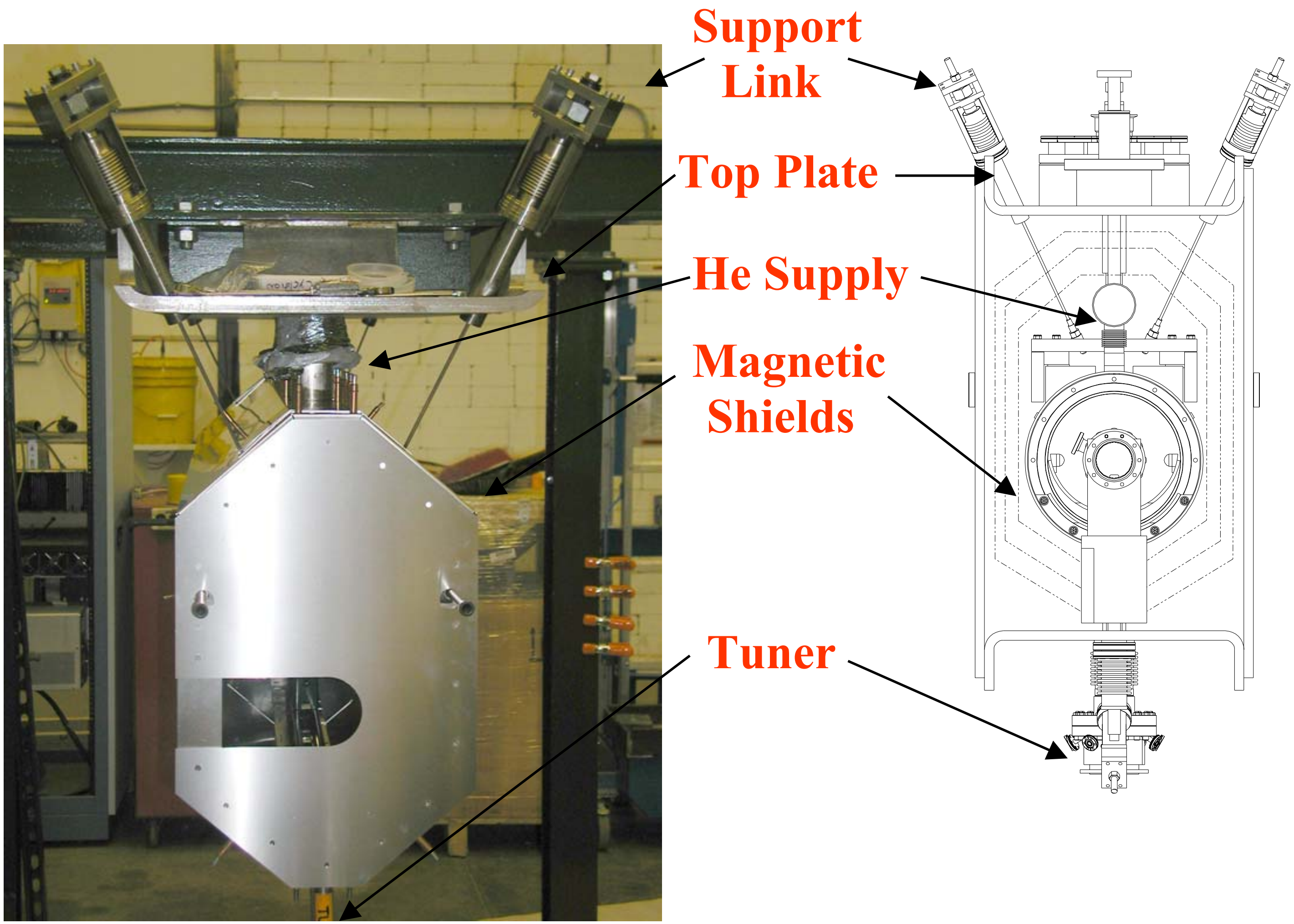


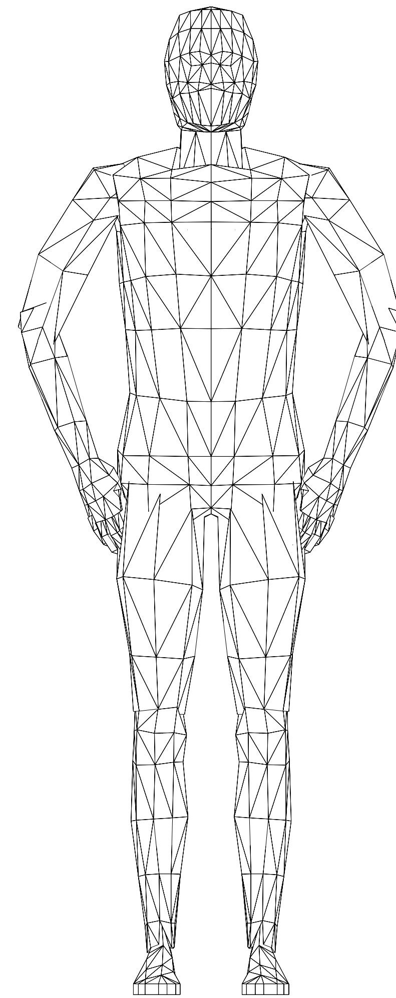
Tuner

Power Coupler



β=0.47 Module End View





805MHz 10kW Amplifier

- THALES TH382 air-cooled vacuum tetrode w/ a TH18482 cavity

International Collaborations

- INFN Legnaro (A. Facco)
  - Drift-tube cavities for RIA
  - Industrial quarter-wave resonator at Zanon
- JLab (P. Kneisel) & INFN Milan (C. Pagani)
  - β=0.49 elliptical cavity and cryomodule
- DESY (S. Simrock)
  - Low-level rf & microphonics control
- TRIUMF (R. Laxdal)
  - λ/4 resonator processing & cryomodule designs
- ACCEL of Germany
  - Low beta cavities

Elliptical Cavities Funding

- Work started in 2000
- Funding from DOE to MSU & JLAB

FY2001	$400k
FY2002	$690k
FY2003	$500k
FY2004	$550k**

**Requested funding to complete Elliptical Cavities R&D

Elliptical Cavities Summary

- Cavity performance demonstrated
  - β=0.47, 0.61 & 0.81 six-cell cavities
- Prototype β=0.47 Cryomodule
  - Cold mass assembled in cleanroom in Sept. 2003
  - Cryomodule assembly complete in 2003
  - Test under realistic operating conditions in 2004
- By end of 2004 elliptical cavity R&D will be complete
- RIA linac design and production plans can be finalized

BACKUPS

National Superconducting Cyclotron Lab (NSCL)

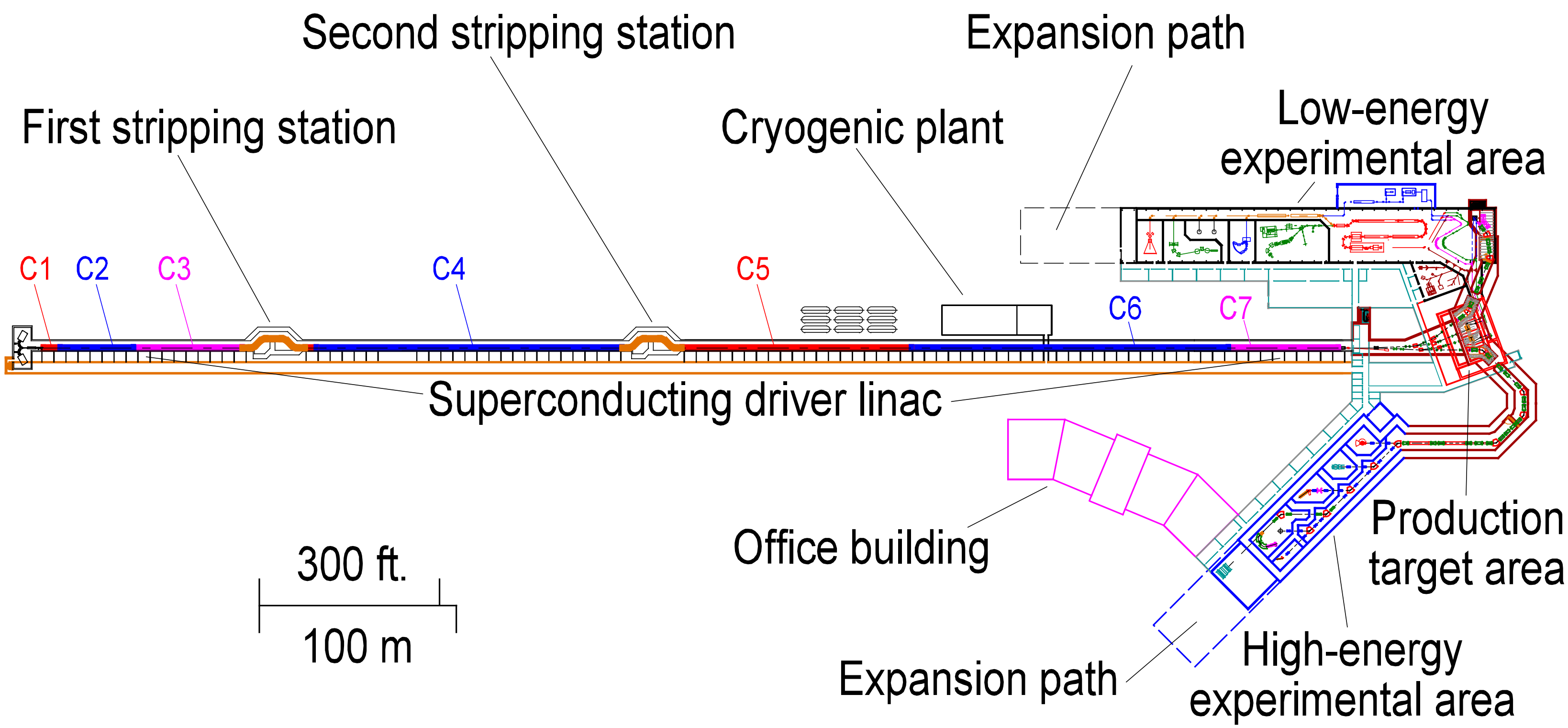
- National user facility for rare isotope research
  - Operations predominantly funded by NSF
  - Basic Research Elements
    - Nuclear Science & Nuclear Astrophysics
    - Accelerator Physics
- About 250 Employees
  - 23 Faculty, ~100 students, ~100 staff
- Recent (2001) initiation of SRF research program
  - Full capabilities in or in vicinity of NSCL
  - Significant graduate student education component

Rare Isotope Accelerator (RIA) Project

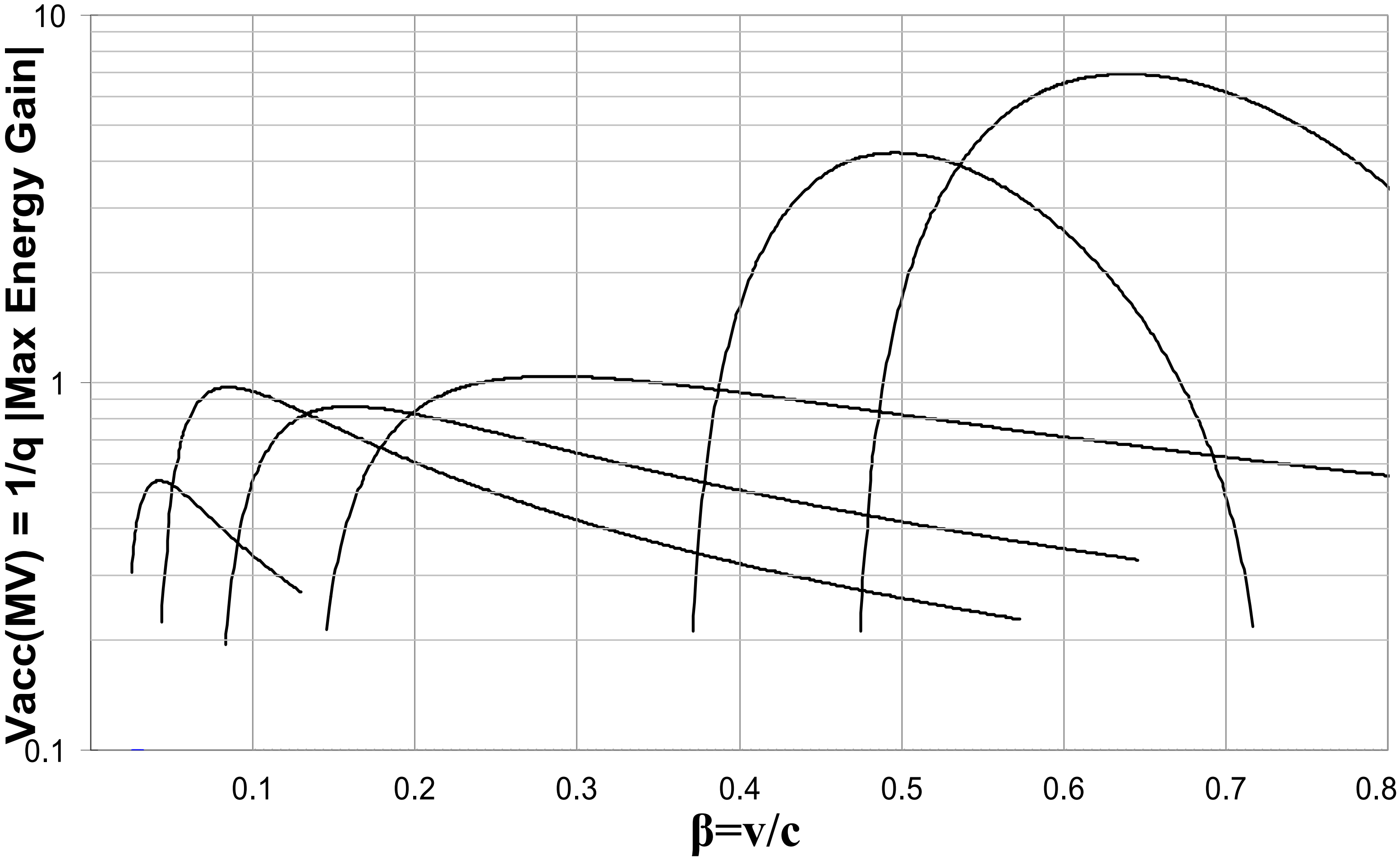
- Nuclear Science Advisory Committee Long Range Plan
  - Highest priority major new construction
- RIA Driver Linac
  - ECR ion sources & RFQ
  - Lower β (0.03 – 0.12) SC structures
  - Medium β (0.12 – 0.26) SC structures
  - High β (0.47 – 0.81) SC structures

Schematic Layout of RIA at MSU

- **Driver linac can be either straight (as shown) or folded**
- **Final choice will be based upon cost/benefit analysis**

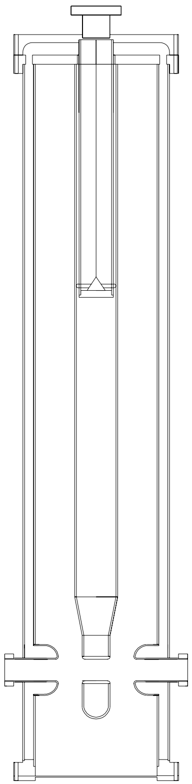


TTs of RIA Driver Linac Cavities

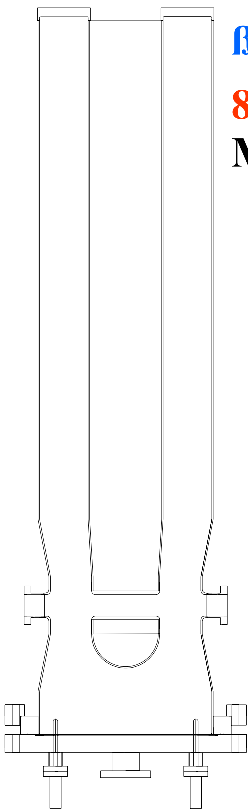


NSCL

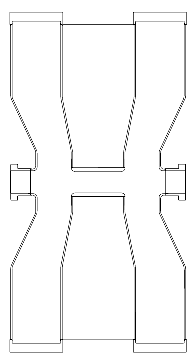
MSU RIA Driver Linac Cavities - [1]



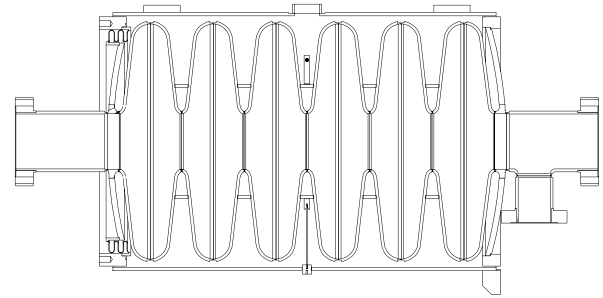
β_{opt}=0.041
80.5MHz
Legnaro ✓



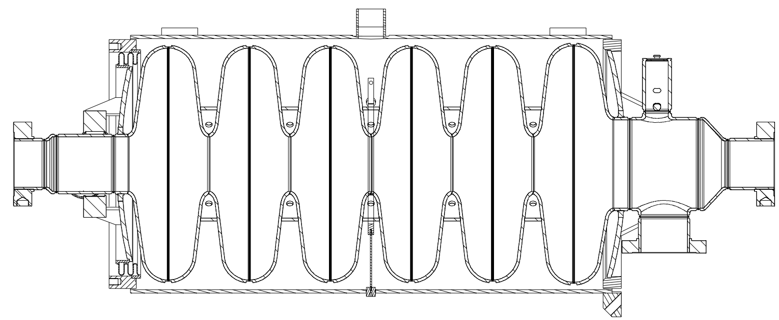
β_{opt}=0.085
80.5MHz
MSU



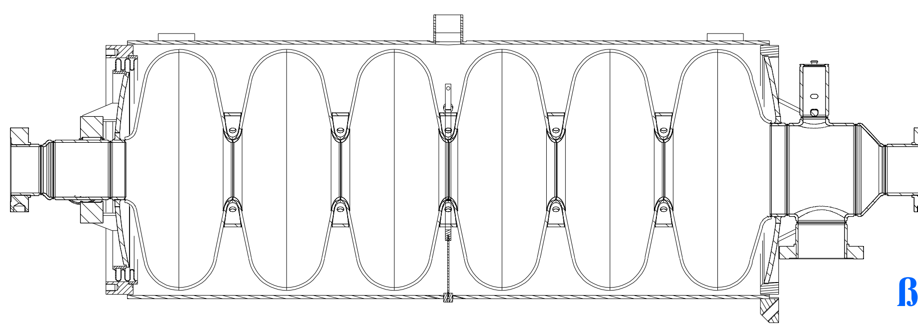
β_{opt}=0.285
322MHz
MSU ✓



β_{opt}=0.49
805MHz
MSU/JLAB ✓



β_{opt}=0.63
805MHz
SNS ✓



β_{opt}=0.83
805MHz
SNS ✓

10^{th} Sub-Harmonic Ria Driver Linac

MSU 10^{th} (80.5 MHz) Sub-harmonic RIA Driver								
Type	RFQ	λ/4	λ/4	λ/4*	λ/2	6-cell	6-cell	6-cell
β_{opt}		0.041	0.07	0.16	0.285	0.49	0.63	0.83
f (MHz)	80.5	80.5	80.5	161	322	805	805	805
V_{acc}(MV)		0.54	0.86	0.86	1.04	4.3	6.89	11.1
T(K)		4.2	4.2	4.2	4.2	2	2	2
Q_o		$2.5x10^8$	$2.5x10^8$	$2.5x10^8$	$2.5x10^8$	$5x10^9$	$5x10^9$	$5x10^9$
P_0(W)		2.74	5.17	7.8	21.8	21.4	34	51.4
U(J)		1.36	2.56	1.91	2.68	21.1	33.6	50.8
R/Q(Ω)		424	571	381	199	173	279	483
R_s(nΩ)		73	104	140	244	31	36	52
E_{peak}(MV/m)		16.2	16.3	16.5	16.5	27.3	27.4	26.9
B_{peak}(mT)		36	38.4	37.8	45.3	53.9	57.8	58.1

$$P_o = \frac{V_{acc}^2}{R}$$

$$Q = \frac{\omega U}{P_o}$$

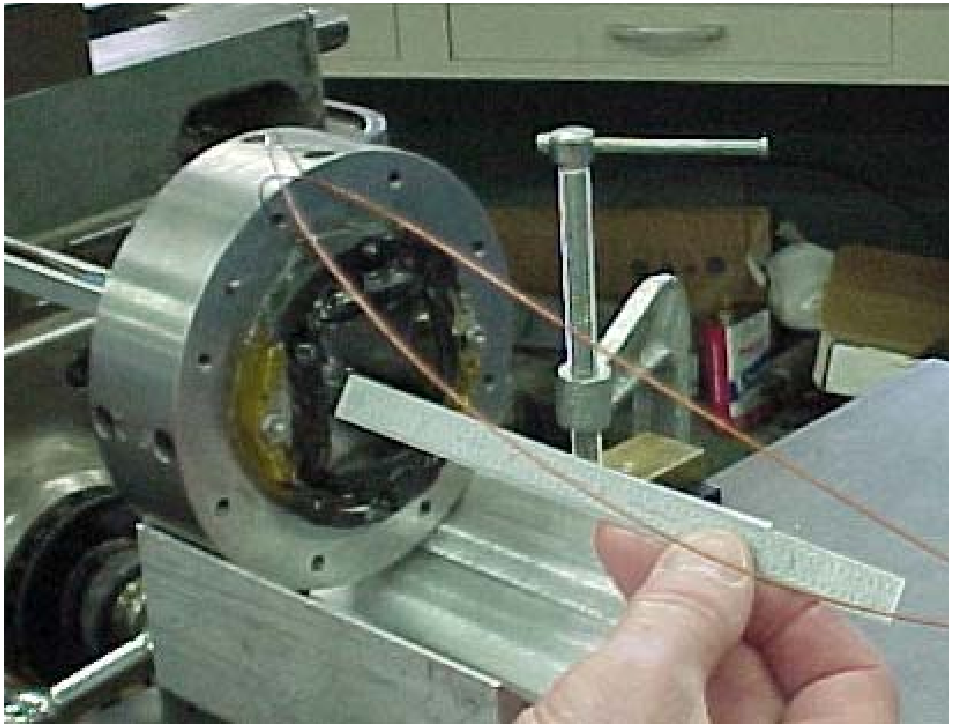
$$\frac{R}{Q} = \frac{V_{acc}^2}{\omega U}$$

*tapered drift tube to cancel vertical steering

$$V_{acc} = \frac{1}{q}\left|Maximum\ energy\ gain\ of\ optimum\ particle\right|$$

Superferric SC Quadrupoles

- Appropriate for SRF Linac applications
- Provides focusing element within cryostat environment



<u>Specifications</u>

<10mG stray field at 10cm
50mm length
40mm bore
31 T/m

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